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VALIDATION OF PROPOSALS FOR THE ENVIRONMENTAL OPTIMIZATION OF A COMPACT-TYPOLOGY KINDERGARTEN, IN A VERY HOT-HUMID CLIMATE[1]

VALIDACIÓN DE PROPUESTAS DE OPTIMIZACIÓN AMBIENTAL DE UN JARDÍN DE INFANTES DE TIPOLOGÍA COMPACTA, EN CLIMA MUY CÁLIDO-HÚMEDO

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1 This work is part of the "Validation of a tool for estimating optimal glazed areas for the passive use of Solar Energy in School Buildings in Urban Areas of the N.E.A. Region" It is also part of the Work Agreement signed under Res. No 134/21 C.D. FAU between the Faculty of Architecture and Urbanism of the National University of the Northeast and the Ministry of Education, Culture, Science, and Technology of the Province of Chaco.

RESUMEN

El siguiente artículo presenta el procedimiento de validación de propuestas de optimización de un prototipo de jardín de infantes de tipología compacta, según pautas de diseño bioclimáticas pasivas, mediante modelos físicos de simulación dinámica calibrados con mediciones *in situ*. El objetivo es verificar los parámetros de área vidriada (Av), absortancia solar promedio ponderada ($\bar{\alpha}$) y área de envolvente total ($A_{envolvente}$) utilizados como datos de entrada para la obtención de correlaciones de Factores de vidriado (Fv), en una herramienta de estimación de áreas vidriadas óptimas orientada a integrar el confort térmico y visual en el diseño de espacios educativos, en el clima Muy Cálido Húmedo de la Región Nordeste Argentina. Como resultado, se obtuvo una reducción de los requerimientos de refrigeración de hasta el 72% en el mes de noviembre, más desfavorable para la actividad escolar, al bajar la absortancia solar de las superficies exteriores a 0.25, con una relación de área vidriada por área de piso de 17% que posibilitó notables mejoras en la distribución espacial de la luz natural, recurso fundamental para el desarrollo integral de los niños del Nivel Inicial.

Palabras clave
energía solar, arquitectura escolar, confort térmico, confort lumínico.

ABSTRACT

This article presents the validation procedure of optimization proposals for a compact-typology kindergarten prototype, following passive bioclimatic design guidelines, using dynamic simulation physical models calibrated with onsite measurements. The objective is to verify the parameters for the glazed area (gA), weighted average solar absorptance (α), and total envelope area (envelopeA), using them as input data to obtain correlations of glazing Factors (gF) into a tool to estimate optimal glazed areas, aiming at integrating thermal and visual comfort in the design of educational spaces, in the Very Hot-Humid climate of the Argentine Northeast. As a result, a reduction of up to 72% was obtained in November, the most unfavorable month for school activities, for cooling requirements, by lowering the solar absorptance of exterior surfaces to 0.25, with a glazed area per floor area ratio of 17%, which made noteworthy improvements possible in the spatial daylight distribution, a key resource for the comprehensive development of children from Initial Schooling Levels.

Keywords
Solar energy, School architecture, Thermal comfort, Light comfort

INTRODUCTION

Several international studies show the direct relationship between classroom indoor environment quality and student learning. In fact, temperature plays a primary role in academic performance (Muñoz, 2018), as does daylighting, which is particularly important for children's physical, cognitive, and emotional development, as they are even more sensitive to its dynamic effects (Montessori, 1998, Chilean Energy Efficiency Agency [Achee, in Spanish], 2012; Yacan, 2014; Monteoliva, Korzeniowski, Ison, Santillan & Pattini, 2016, Pagliero Caro & Piderit Moreno, 2017, Extremeña Energy Agency [AGENEX, in Spanish], 2020).

However, finding the balance between hygrothermal and light living conditions in regions with harsh climates is not an easy goal to achieve using passive design strategies, even more so in the context of global climate change, whose extreme weather events are becoming more frequent (IPCC, 2019). In these areas, ensuring optimal indoor conditions has a direct environmental impact on energy consumption levels and their consequent CO_2 emissions to the atmosphere (Baserga, 2020). In addition, the epidemiological situation generated by the Covid-19 pandemic, where sunlight, daylighting, ventilation, and social distancing (Cistern and Abate, 2021) have become key in the use of educational infrastructure, has highlighted the need for new comprehensive approaches, models and solutions.

In this vein, numerous research projects (Trebilcock, Soto, Figueroa & Piderit, 2016; Souza, Nogueira, Lima & Leder, 2020; Coronado, Stevenson-Rodriguez & Medina, 2021; Lamberti, Salvadori, Leccese, Fantozzi & Bluyssen, 2021; Rupp, Vásquez & Lamberts, 2015) have questioned the use of conventional comfort standard in schools, as they were developed based on adult subjects whose comfort perceptions and preferences may differ from those of children in various stages of development, demonstrating the need for a local view in Latin American, not just from the aspects of energy-saving and operational costs, but mainly regarding physiological, psychological, social, and cultural variables. However, the evaluation of thermal comfort in kindergartens is a recent topic and only a few works can be found in the specialized literature (Lamberti *et al.*, 2021: Yun *et al.*, 2014; Fabbri, 2013; Nam, Yang, Lee, Park & Sohn, 2015, Zomorodian, Tahsildoost & Hafezi, 2016). Also, there are no metrics to evaluate the daylighting intended exclusively for kindergartens or children's spaces.

One of the passive design variables of educational buildings, which has been and is widely studied for its impact on both energy performance and integrated environmental comfort, is the optimal layout of glazed areas considering the envelope area exposed to solar radiation. This also includes the effects of random variation in the occupation (Ochoa, Aries, van Loenen & Hensen, 2012; Lartigue, Lasternas & Loftness, 2014; San Juan, 2014; Futrell, Ozelkan & Brentrup, 2015; Mangkuto, Rohmah & Asri, 2016; Capeluto, 2019; Chiesa *et al.*, 2019; Filippín, Flores Larsen & Marek, 2020; Ré & Bianchi, 2020).

In the work of Ochoa *et al.* (2012), discrete variations of the window-wall ratio were studied, and it was concluded that most of the project expectations can be met within a variety of sizes, provided they have additional control devices. Lartigue *et al.* (2014), as well as Futrell *et al.* (2015), also considered the window type characterized by its visual and thermal properties, observing that, depending on the orientation, the thermal and daylighting objectives may clash greatly. Alwetaishi (2019) analyzed the impact of modifying the window-wall ratio in different climatic zones of Saudi Arabia, recommending 10% in hot and dry climates, as well as hot and humid ones, and 20% in moderate climates. Pérez and Capeluto (2009), on the other hand, tested a base case in the warm–humid climatic zone using computer simulation, and recommended, for north and south-facing windows, 12% of the classroom floor area. For west and east-facing areas, it is preferable to reduce the window size to 10% of the floor area, with dynamic shading devices to avoid glare due to lower solar angles. Not only the window size, but also its orientation, have a great effect on internal conditions, being the main aspect responsible for determining the degree of sun exposure and, therefore, direct heat gain (Gasparella, Pernigotto, Cappelletti, Romagnoni & Baggio, 2011, cit. in Alwetaishi, Alzaed, Sonetti, Shrahily & Jalil, 2018).

Considering the problem, an analysis of a particular case of the city of Resistencia, Chaco province, in the Northeast Region of Argentina (NEA, in Spanish) is presented, characterized by very hot-humid weather to check, by simulation, the relevance of the glazed areas proposed as optimal regarding different design variables of its constructive envelope. The original contribution of this work lies in the procedure for evaluating thermal and lighting issues simultaneously, whose objective is to validate a tool for estimating glazed areas by orientation, developed for school typologies of the NEA region and that can be extrapolated to other geographical regions with a hot - humid climate.

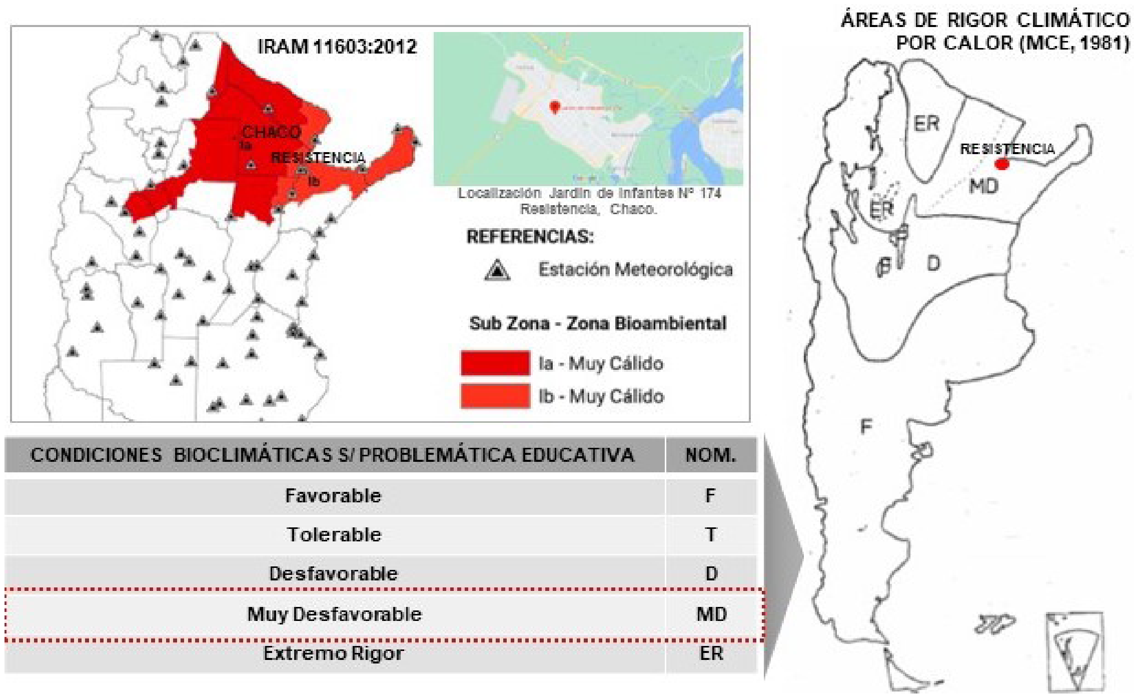

Figure 1. Location of the study area. Source: Preparation by the authors based on bioenvironmental classification maps using IRAM 11603:2012 and MCE (1981).

METHODOLOGY

BACKGROUND

According to the Argentine bioclimatic zoning (Figure 1), considering the influence of climate on educational problems (Ministry of Culture and Education [MCE, in Spanish], 1981), Resistencia (27.45° Lat. South; 59.05° Long. West; Alt. 52 masl) is located in a "Very Unfavorable due to Heat" bioclimatic zone, presenting 6 to 8 months, which cover a large part of the school period, with an average maximum temperature equal to or greater than 28°C, and with the influence of humidity that exacerbates the feeling of discomfort due to heat. This region corresponds to the Bioenvironmental Zone Ib "Very Hot and Humid" climate, according to IRAM 11603 (2012), and is characterized by thermal amplitudes of less than 14°C, maximum temperatures above 34°C, and an average daily global solar irradiation of 5.5 kWh/m^2 in November (the last full month of the common school period), with an average effective heliophany of 8 hours (Grossi Gallegos & Righini, 2007).

Associated with this, the urban sector of Resistencia is located at mid-orientation (45° with respect to the true North), so the glazed areas of the buildings receive solar radiation in all seasons of the year. These are actually areas that are blocked with curtains or other devices that prevent optimal use of daylight. The current regulations (General Building Regulations, 1990; National Ministry of Education and Culture [MCEN, in Spanish], 1996) do not comprehensively consider the climate and location features of Resistencia, so the design decisions, regarding the determination of lighting and ventilation openings, are subordinate to percentage values by floor area, uniform for each orientation, and without consideration of the morphology, degree of exposure, and the materialization of the envelope of buildings, nor their occupation system.

In response to the issues raised in a previous study, Boutet & Hernández (2020) developed a tool for Estimating the Glazing Factor (gF) using Multivariate Linear Regression (MLR), to calculate the optimal glazed areas of open (with two lighting and ventilation fronts; greater exposed envelope surface) and compact (with a single front) typology school buildings of the different educational levels (preschool, primary, secondary, and high school). The Glazing Factor, *gF* (dependent variable), is a new parameter defined by the authors that allowed connecting the (independent) variables considered as most significant by orientation, given their incidence on thermal balance: weighted average solar absorbance () of the opaque exterior surfaces, considering their finishing color (implies the fraction of incident solar radiation that is absorbed by the envelope materials); glazed area of doors and windows (gA); and the total opaque and glazed envelope area ($_{envelope}A$). This relationship is expressed in the following equation [Eq. (1)]:

Revista Hábitat Sustentable Vol. 12, N°. 1. ISSN 0719 - 0700 / Págs. 24 -43
https://doi.org/10.22320/07190700.2022.12.01.02

$$F_v = \frac{\bar{\alpha} . A_v}{A_{exp}} \qquad (1)$$

Where, *Fv*: Glazing Factor of each room by orientation; : weighted average solar absorbance of all exterior surfaces; $_{g}A$: total area of glass in windows and doors exposed to the outside; $_{exp}A$: area of facades and roofs exposed to the outside, discounting *gA*. Then $_{exp}A$ = $_{envelope}A$ - $_{g}A$.

From this factor, the equation to calculate the optimal glazed area is cleared, where an inversely proportional relationship with the solar absorbance is verified [Eq. (2)]. The higher the absorbance value (darker surface), the smaller the admissible glass area.

$$A_v = \left(\frac{F_v}{F_v + \bar{\alpha}}\right) A_{envolvente} \qquad (2)$$

Based on this new factor and its determination in a Generic Optimization Proposal, it was possible to formulate the proposed tool, which is the result of a statistical analysis of dynamic simulations calibrated with annual measurements of the hygrothermal and light behavior of 8 school buildings of different educational levels, selected because of their high sun exposure. The Generic Proposal verified the necessary habitability conditions, with the consequent reduction of air conditioning loads by between 40 and 60% on average (Boutet & Hernández, 2021).

Based on this information, in this work, it was proposed to make a review of the input data used to obtain correlations of Glazing Factors (*Fv*) of the initial level compact typology (Kindergarten N° 174), selected among the 8 buildings monitored at the time. To do this, the relevance of the glazed areas proposed for different solar absorption values was verified by simulation, in the month of November, as this is the most unfavorable school season (warm atmosphere, solar gain through the windows, and higher level of activity), which entails overheating situations. The aforementioned revision makes it possible to make a preliminary validation of the Glazing Factor (*Fv*) estimation methodology, which leads to new analysis situations that, in short, statistically reinforce its formulation.

VALIDATION PROCEDURE

The validation procedure using dynamic simulation consisted of the following methodological steps, presented in the flow diagram of Figure 2:

a. **Review of energy audits,** carried out during the period from November 12th to November 19th, 2012 in Kindergarten No. 174 using HOBO MOD U12-012 (T°C/%RH/Lx) data acquirers. and an ONSET (USA) H21-002 Microstation that was installed in the urban area where the building is located, to obtain accurate microclimatic conditions. This activity involved complementary objective observations, surveys of teachers and authorities, and daily recording of user behavior patterns.

b. **Validation of physical models.** With the measurements, the hourly temperature data obtained by SIMEDIF *V2.0* (Flores Larsen, 2019) and the illuminance data obtained by exporting

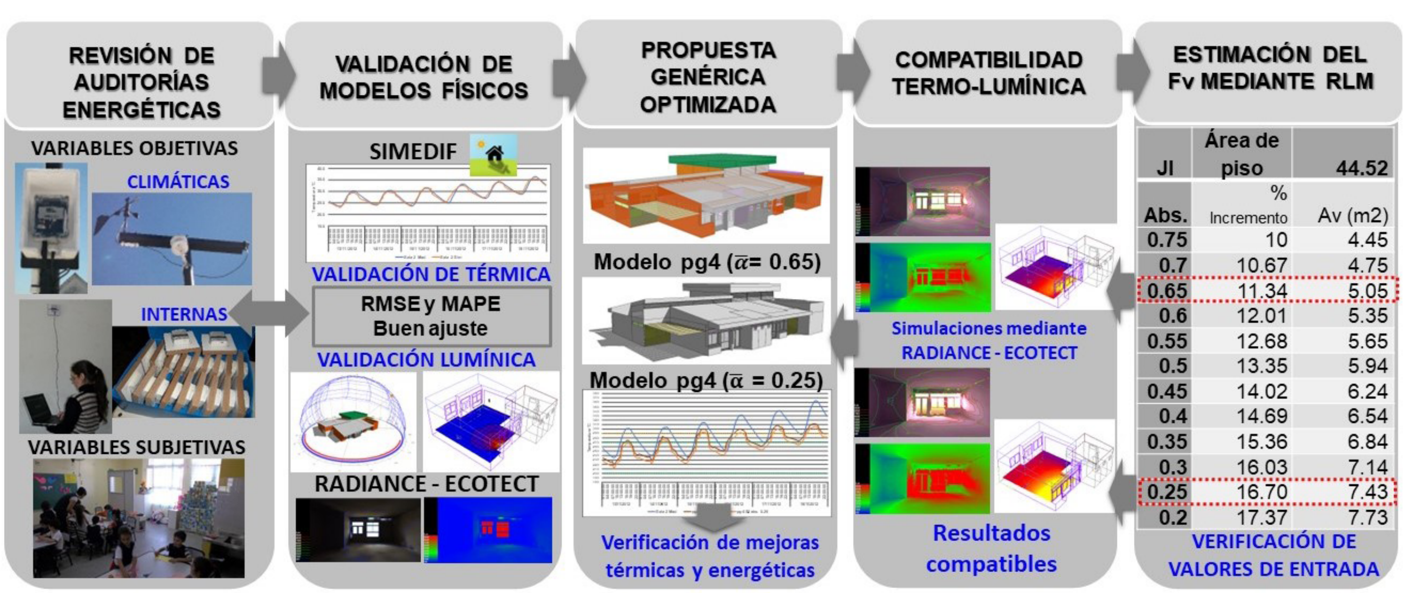

Figure 2. Methodological steps. Source: Preparation by the authors.

them to the RADIANCE interface of Autodesk Ecotect Analysis, were validated. Two indices were used: the Root Mean Square Error or RMSE [Eq. (3)], which quantifies the magnitude of deviation between the measured and simulated values in terms of units of variables by the square root of the mean square error, and the Mean Absolute Percentage Error or MAPE [Eq. (4)] performance indicator, that measures the size of the relative error as percentages (%).

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}[(x_{med})_i - (x_{sim})_i]^2}{N}} \quad (3)$$

$$\mathrm{MAPE} = \frac{\sum_{i=1}^{n} \frac{|x_{med} - x_{sim}|}{|x_{med}|}}{N} \quad (4)$$

Where, Xmed : measured values; -Xsim: simulated values; and N- number of measurements.

c. **Optimized Generic Proposal.** The obtained models were used to simulate the thermal and light behavior of the prototype, in the same period of November, applying the Optimized Generic Proposal (Boutet & Hernández, 2021) for different solar absorbance values of the exterior surfaces (α= 0.65 and 0.25). The reduction percentage of cooling loads was also verified, through simulations with thermostatization in Simedif, setting a temperature of 25°C. This value is the comfort temperature recorded from the monitoring and at which the air conditioning equipment in schools is usually regulated.

d. **Thermo-light compatibility.** The average illuminance totals (lx) calculated using Radiance - Ecotect, were compared with the corresponding temperature obtained by Simedif, at three times (9 am, 1 pm, and 4 pm) on the sunniest day, to verify whether thermal well-being is compatible with adequate daylight, considering the local comfort ranges established. A winter thermal comfort zone of 20 to 25°C and a summer comfort zone of 25 to 29°C are considered reference values at a regional level but for the statistical analysis, based on the regional limit values and the representativeness of the variables measured throughout the monitoring year, an average temperature range of 20 to 27°C and of 35% to 65% RH was defined, values that are also consistent with international standards (Boutet, Hernández & Jacobo 2020). For the illuminance analysis, the range of 300 to 500 lx (up to a maximum of 750 lx), recommended by IRAM AADL J-2004 (1974) and MCEN (1996) Standards, was considered.

Estimation of *Fv* by Multivariate Linear Regression. The verification of the relevance of the input data of the Glazing Factor (*gF*) estimation tool, for the Compact Kindergarten Typology, is concluded, highlighting its implications and the importance of the findings obtained.

DESCRIPTION OF THE CASE STUDY

Kindergarten No. 174 is a representative prototype of the official school architecture used in the province of Chaco, through the More Schools National Program. It is located in the San Miguel de Resistencia neighborhood, a residential area with low building density. It was opened in 2010, with a total covered surface area of 573 m². It is a compact typology building with 4 symmetrical classroom modules of 49 m² each, integrated into pairs by sliding panels, including semi-closed SUM. It has exposed surfaces towards the 4 middle orientations, without external solar barriers (Figure 3). It is characterized by its traditional technology, which is described in Table 1.

Figure. 3. Location of Kindergarten No. 174 and photo of its main entrance. Source: Preparation by the authors.

Revista Hábitat Sustentable Vol. 12, N°. 1. ISSN 0719 - 0700 / Págs. 24 -43
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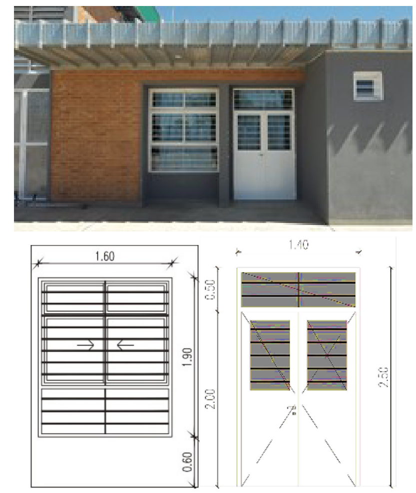
Walls	Masonry comprising 0.20 thick reinforced common load-bearing bricks, visible on the outside and coated inside	
Roofs	Ventilated self-supporting sheets (aerators every 2m) on a metal structure with glass wool insulation with aluminum foil.	
Ceilings	Plaster sheets on the inside or applied under the slabs of galleries and services	
Floors	30 x 30 cm granite mosaics inside and in galleries and 15 x 15 cm in wet areas	
Openings	Each classroom has 3 1.60 x 1.90 m openings of double glazed frames N°16 and aluminum sheets with 3+3 mm laminated glazing, located one towards the outside and two towards the non-exposed interior, formed by sliding and fixed panels. The doors have a fixed upper panel and two folding sheets, with 3+3 mm laminated glass.	
Protections	Security bars and roof eaves. Internal curtains on doors and windows. Sunshades of different sizes with fixed double sheet N°16, and latticework-type panels on the SUM and the galleries	
Fittings	Classrooms: 5 fluorescent 2 x 36 W tubes and 2 industrial wall fans. SUM: 9 industrial 250 W hanging lamps and 5 30" industrial wall fans	

Table 1. Constructive characteristics of the JI N° 174. Source: Preparation by the authors.

Figure 4. Natural ventilation layout. Interior and exterior photos of the SUM. JI 174. Source: Preparation by the authors.

Although the building typology studied is compact, the semi-enclosed spaces (SUM and corridors) allow diffuse daylighting and permanent cross ventilation through the rooms' interior and exterior windows. This, in turn, leads to inconveniences, like the entry of dust, ventilation, and lighting during unfavorable weather, acoustic problems, and water leaks on rainy days (Figure 4).

RESULTS AND DISCUSSION

ENERGY AUDITS

The monitoring period covered eight days, from Nov. 12th, 2012 at 1 pm to Nov. 19th, 2012 at 1 pm. Two opposite-facing rooms with the same constructive characteristics were analyzed (Figure 5). Room 2 (H18) had two exposed northwest-facing facades and glazed areas, and Room 3 (H19), with one southeast-facing exposed facade and glazed areas. Room 2 was occupied in the morning (from 8 am to 12:45 pm), with 24 children aged 3 and 4, and Room 3, in the afternoon (from 1:30 pm to 5:45 pm), with 22 children aged 4 and 5. The SUM (H20) was also monitored. Classes were held normally during the working week, except on the 15th, 16th, and 19th, since there were no classes. Data provided by the Provincial Billing Company (SECHEEP, in Spanish) indicated that the Kindergarten had a consumption of 909 kWh in November, this being the highest of the spring period.

Figures 6, 7, and 8 compare the internal and external variables measured concerning the regional comfort ranges.

The temperature curve trend of room 2 morphologically responds to changes in outside temperature, with very pronounced peaks and troughs, and is outside the

Revista Hábitat Sustentable Vol. 12, N°. 1. ISSN 0719 - 0700 / Págs. 24 -43
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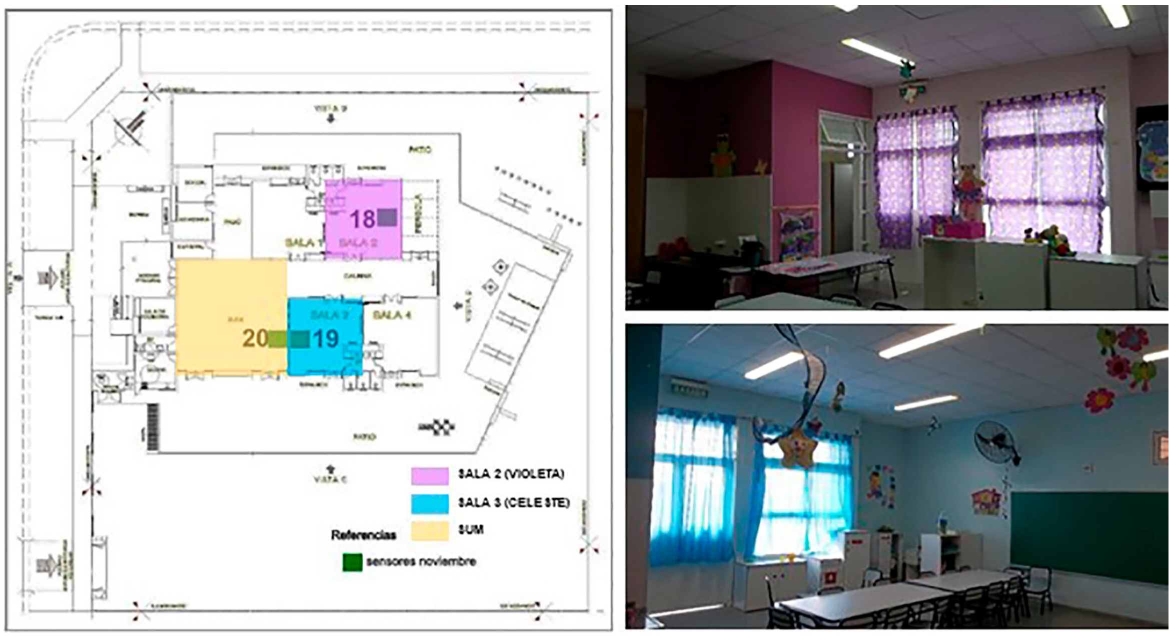

Figure 5. Left: JI 174 monitoring scheme. Period Nov. 12th, 2012 – Nov. 19th, 2012 Right.: Interior Room 2 (Violet), with NW-facing windows, and Room 3 (Light Blue), with SE-facing windows.

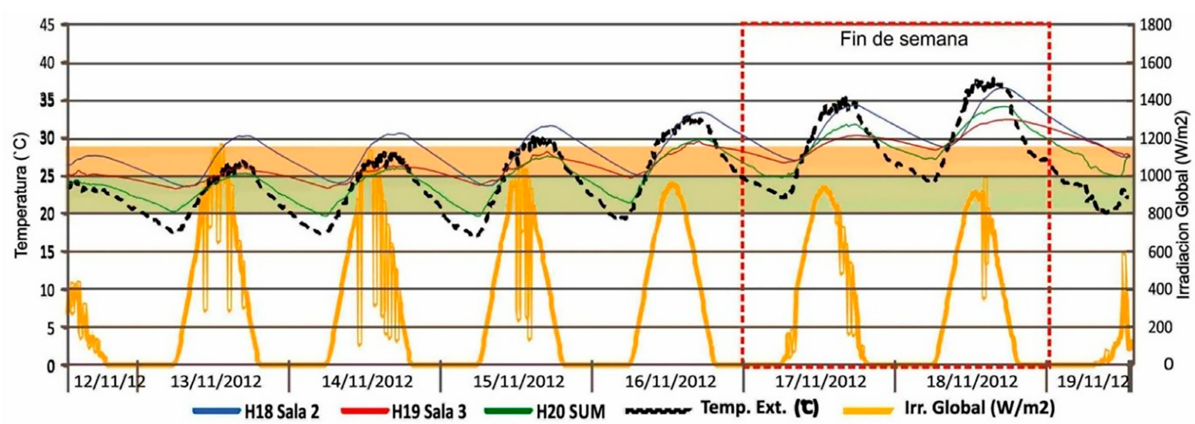

Figure 6. Evolution of internal temperatures. Classrooms JI 174. Period Nov. 12th. 2012 – Nov. 19th, 2012. Source: Authors' record.

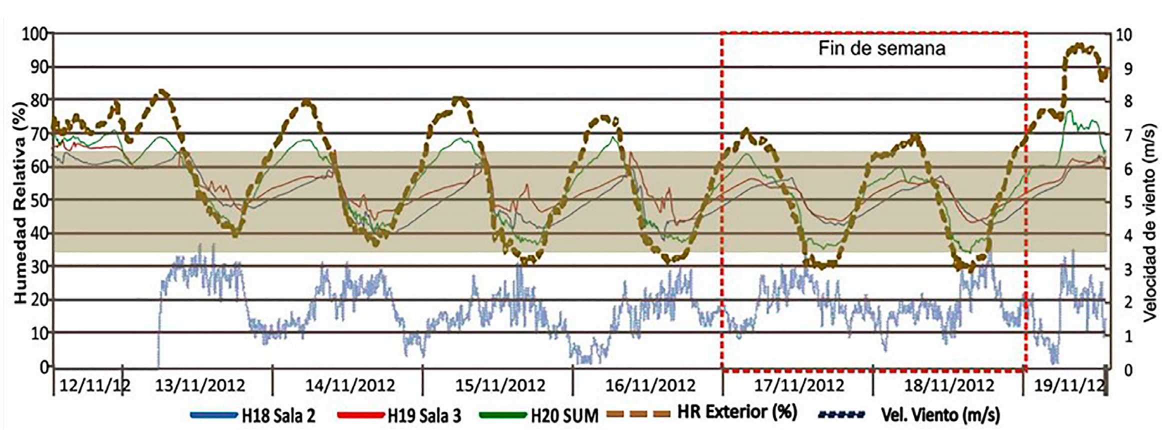

Figure 7. Relative humidity evolution. Classrooms JI 174. Period Nov. 12th, 2012 – Nov. 19th, 2012.
Source: Authors' record.

Revista Hábitat Sustentable Vol. 12, N°. 1. ISSN 0719 - 0700 / Págs. 24 -43
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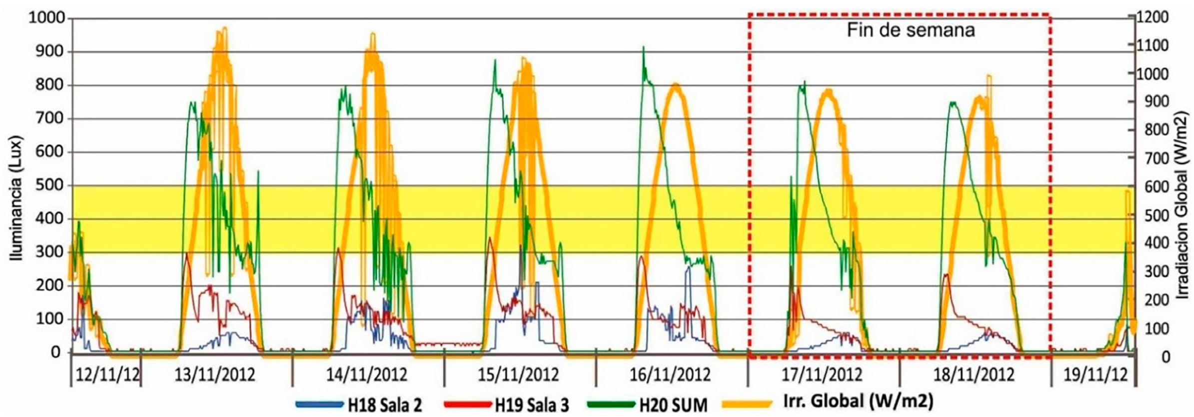

Figure 8. Evolution of illuminances. Classrooms JI 174. Period Nov. 12th, 2012 – Nov. 19th, 2012. Source: Authors' record.

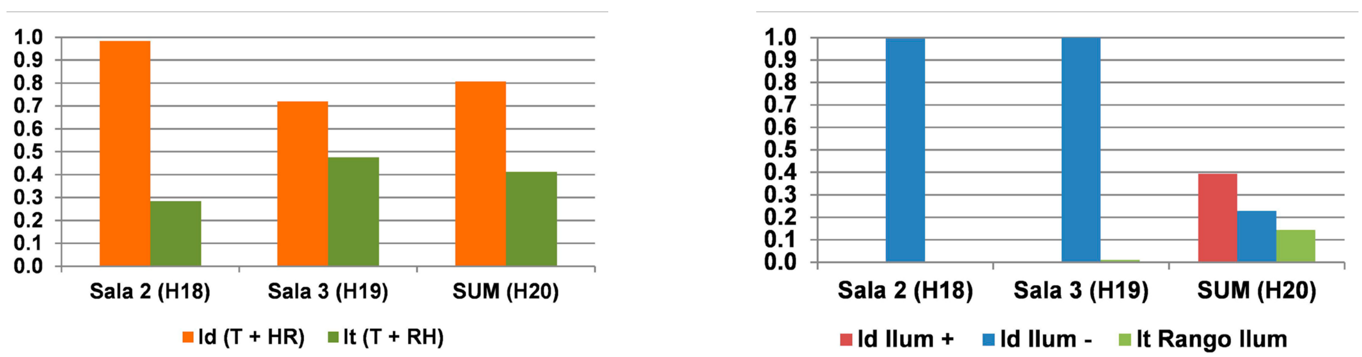

Figure 9. Comparison of combined hygrothermal indices (left) and light indices (right) of monitored premises JI 174. Period Nov. 12th, 2012 – Nov 11th, 2012. Source: Preparation by the authors.

upper comfort limit most of the time. Even though the occupancy schedule is from 8 am to 12:45 pm, this discomfort is confirmed from noon and remains until late at night in the first days, and during the 24 hours, in the last three days of monitoring. Its average values were 29°C – 50% RH, 7.4°C of thermal amplitude and 3.3°C of indoor-outdoor difference, and an average maximum of 32.7°C. The maximum internal temperatures occurred between 4 and 6 pm, while the maximum illuminances, between 2 and 3 pm, so the overheating produced is not due to direct solar gains. It is inferred that this is produced by the combined effect of the incident solar radiation on the entire opaque and glazed envelope and the outside temperature. The curve of room 3 has a more constant behavior since it receives sunlight in the morning, but it is occupied in the afternoon, observing small increases in the occupation hours (1:30 5:45 pm) that last until the evening. The SUM fluctuates almost accompanying the outside temperature, within the comfort band, except on warmer days. The relative humidity of the rooms is kept within the comfort zone, but the SUM exceeds the upper limit.

Consequently, in the period evaluated, room 2 with the largest exposed envelope area had the highest hygrothermal discomfort index [Id (T+RH)], a result of overheating, since it has glazed areas to the northwest, and its northeast facade is totally exposed to solar radiation. On the other hand, both rooms had the highest indices of visual discomfort due to a lack of daylight use [Id Ilum -] (Figure 9). The Id (T+RH) combined discomfort index by temperature and RH, is a relative index between the indoor and outdoor discomfort situation, calculated as the quotient between two observable frequencies. Its complement is the It (T+RH), temporary comfort index. The Light indices I_d *Ilum*$^-$, low illuminance discomfort index, I_d *Ilum*$^+$, excess illuminance discomfort index, and temporary visual comfort index *It* $_{(Ilum\ Range)}$, were calculated considering the established visual comfort ranges when the solar irradiation was greater than 500 W/m^2 (average value of sunny days). Its theoretical development can be consulted in the work of Boutet, Hernández, and Jacobo (2020).

RESULTS OF MODEL VALIDATION

In both simulation programs (Simedif V 2.0 and Radiance – Ecotect) the meteorological data measured in the considered period were entered and

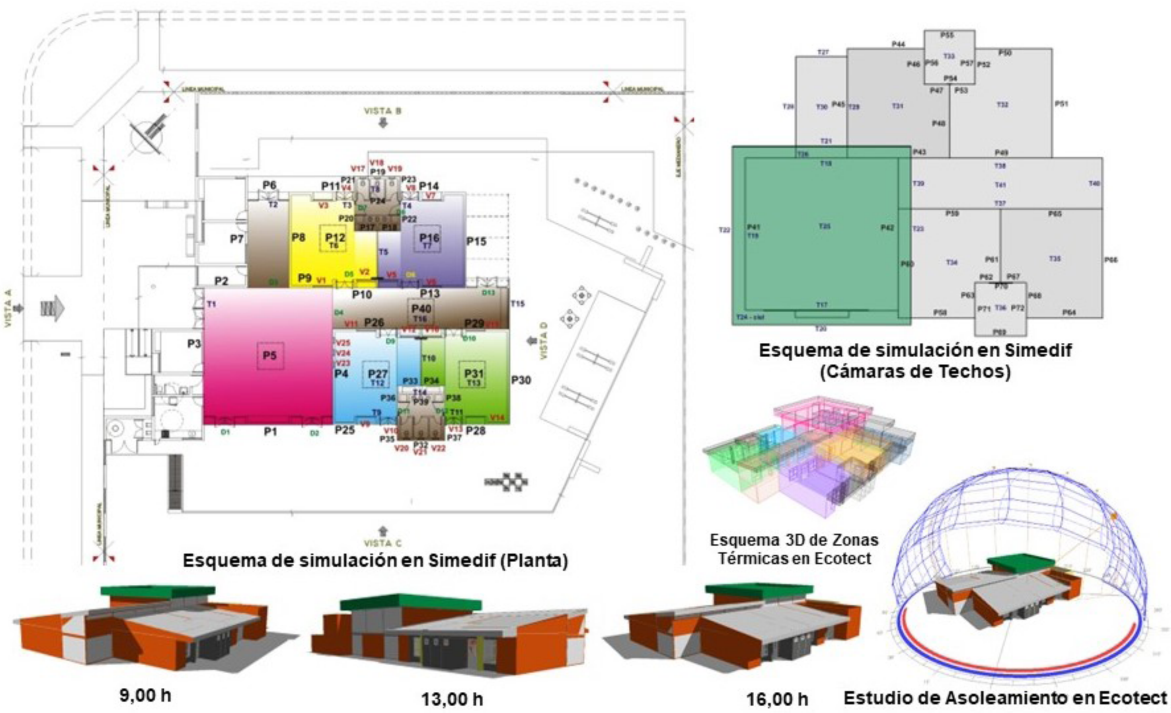

Figure 10. Simulation Models in Simedif and Ecotect. JI 174. Source: Preparation by the authors.

17 thermal zones were defined (Figure 10), including roof air chambers, with standardized parameters in terms of characteristics and physical properties of the building's opaque and glazed components.

Thermal Model. In the model set up in Simedif, 15 days of previous calculation were determined to reach the stable state and the following parameters were specified:

Gains/losses: This comes from people with a moderate level of activity and air conditioning devices, which deliver/extract heat, establishing their power, quantity, and period of use or occupation.

Air renewals (hourly; unit: 1/h): They were differentiated for each day and each zone, considering the voluntary air intake through windows, whose registration was between 0.5 and 4 during the night (without occupation) and between 4 and 10 during the day (with occupation).

Materials and properties of elements with mass and lightweight partitions: They were established from the list of materials available in the program (based on the Argentine IRAM Standards). For others that were not available, the physical properties obtained from tables (Incropera & de Witt, 1999), contrasted with the IRAM Technical Standards, were used.

Global convective/radiative heat transfer coefficients h (W/m2 °C): The external convection-radiation transfer coefficients were defined considering the average wind speed and regarding its impact on the building under study. These varied between 8 and 12 W/m^2°C. The internal values were obtained from Duffie and Beckman (1991), establishing 6 W/m^2°C for shaded surfaces; 8 W/m^2°C, for sunny surfaces; and 3 W/m^2°C, for the lower surface of the ceilings (layered air). For the windows, thermal transmittance of 5.8 W/m^2°C was applied, in the analyses without sun protection, and 2.8 W/m^2°C, in the analyses with protection (internal curtains).

Solar absorbance (value between 0 and 1): This was chosen based on the tables of Incropera and Witt (1999) and the color window provided by the software, determining a value of 0.65 for exposed brick walls, and 0.3 for light-colored surfaces.

Sunny areas: The use of the BIM model configured in Ecotect (Figure 10) contributed to its definition, which allowed obtaining the percentages of shaded and solar radiation-exposed surfaces. The irradiated internal areas were established as equivalent to the glazed area of the analyzed premises that the solar radiation passes through.

Lighting model. For the analysis of daylighting using the Ecotect Radiance interface, the most representative type of sky was defined considering the onsite measurement time, using the CIE (International Commission on Illumination) model. The calculation of the daylighting levels (lx) was made three times,

Revista Hábitat Sustentable Vol. 12, N°. 1. ISSN 0719 - 0700 / Págs. 24 -43
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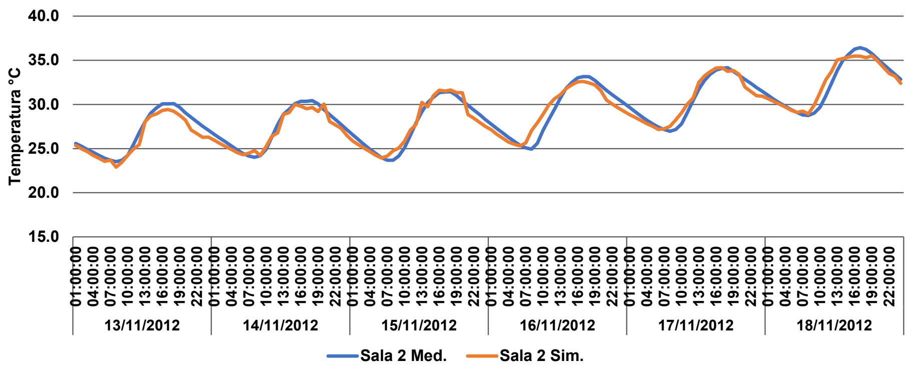


Figure 11. Contrast of measured and simulated temperatures. Room 2 JI 174, period Nov. 13th, 2012 – Nov. 18th, 2012. Source: Preparation by the authors.

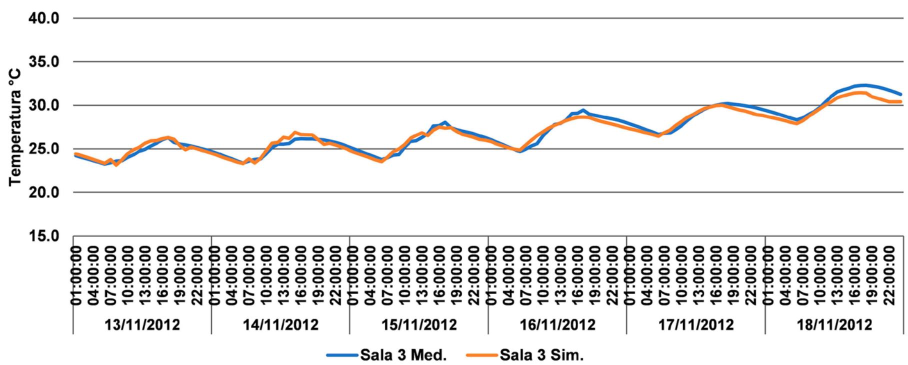


Figure 12. Contrast of measured and simulated temperatures. Room 3 JI 174, period Nov. 13th, 2012 – Nov. 18th, 2012. Source: Preparation by the authors.

JI 174 - NOV.	RMSE (T °c)			MAPE (T %)		
LOCAL	Full Per.	Class days	Days unoccup.	Full Per.	Class days	Days unoccup.
Room 2 (H18)	0.7	0.7	0.8	2.1	2	2.1
Room 3 (H19)	0.5	0.4	0.5	1.5	1.2	1.6
SUM (H20)	0.7	0.5	0.8	2.2	1.8	2.4
AVG. TOTALS	0.6	0.5	0.7	1.9	1.7	2.0

Day Nov. 14th, 2012			Meas. Illum (Lx)	Sim. Illum (Lx)	RMSE (LX)	MAPE (%)
Room 2 (H18)	1	9 am	114	111	17	30
	2	1 pm	83	79		
	3	4 pm	35	65		
Room 3 (H19)	1	9 am	99	108	8	6
	2	1 pm	130	141		
	3	4 pm	99	108		
SUM (H20)	1	9 am	777	931	114	18
	2	1 pm	430	552		
	3	4 pm	201	211		
TOTAL AVERAGES					46	18

Table 2. Adjustment between measured values and simulated values with SIMEDIF. Source: Preparation by the authors.
Table 3. Adjustment of illuminances day 14/11/2012. Source: Preparation by the authors.

Revista Hábitat Sustentable Vol. 12, N°. 1. ISSN 0719 - 0700 / Págs. 24 -43
https://doi.org/10.22320/07190700.2022.12.01.02

at 9 am, 1 pm, and 4 pm on the sunniest day (Nov. 14th, 2012), in an analysis grid that was configured for each classroom at the height of the work plane (0.60 m for the children). Visualizations were established that represented the amount of incident light on each interior surface, with the illuminance values in "contour lines" and in "false color". To configure the use of internal curtains, the visible transmittance of the glazed areas was regulated following the different situations observed during the monitoring. Although this is a simplification, it was relevant for the required conceptual analysis, although a more detailed analysis is expected in future studies, for which the application of annual dynamic metrics is recommended, which would allow a better characterization of the visual environment.

As global averages of the evaluated premises, the values of the Root Mean Square Error - RMSE (°C) of the temperature of the premises simulated with Simedif show mean deviations of 0.6 throughout November, 0.5°C on the class days, and 0.7°C on the days without occupation. The total averages of the Mean Absolute Percentage Error - MAPE (%) are 1.9% in the full period, 1.7%, on class days, and 2.0%, on the days without occupation. In both cases, a greater adjustment was confirmed during school days (Figures 11 and 12; Table 2).

The differences in the illuminance averages measured and simulated using the Ecotect Radiance interface on the considered day resulted in an RMSE value of 46 Lx and a MAPE value of 18% on average (Table 3).

The global thermal and light adjustment orders found, demonstrate the validity of the physical models made in Simedif, using the Ecotect program as support for solar and lighting analysis, which allowed continuing with the testing of the generic proposal optimized for the case study.

OPTIMIZED GENERIC PROPOSAL

In the work of Boutet and Hernández (2021), after testing multiple improvement proposals for the audited cases, which were verified for the different seasons of the year, a Generic Proposal was defined with five alternatives and in two series (light and dark fittings), among which the so-called "*pg4*" was selected as the most optimal from the technical-economic point of view and its thermo-luminous behavior, to be applied to the case studies. The new values of *gA*, and *envelopeA* obtained in this research were used as input data for the Glazing Factor (*gF*) estimation tool, using Multivariate Linear Regression (MLR). In this second part of the research, the study of the proposal applied to Kindergarten No. 174 was developed further to verify its relevance, detecting the potential bioclimatic resources of the building and specifying the following design guidelines:

- Modification of the proportions of glazed areas in windows and doors for two weighted average solar absorbance values: *pg4* (= 0.65) with a glazed area of 5.05 m^2 and *pg4* (= 0.25) with a glazed area of 7.43 m^2, extracted from the input data corresponding to the *gF* estimation methodology (Boutet & Hernández, 2020). In this way, the GA/FA (Glazed Area / Floor area) improved from 7.4% when it did not meet the 10% value recommended by the Construction Regulations, to 11.3% in *pg4* (= 0.65) and 16.7% in *pg4* (= 0.25) and, consequently, the GA/FA (Glazed Area / Facade Area) values increased from the original 20% to 31% and 46%, respectively.

- Integrated design of solar protection devices in different geometric configurations appropriate for mid-orientation. Given that the building geometry of JI N° 174, with panels sunk and jutting out, generates a certain degree of solar protection to the openings, the (0.50 m wide) exterior light shelves solution was feasible with a reflective finish along the higher glazed panes (at 2.10 m in height), and an interior light shelf (0.40 m wide) to improve the daylight distribution and decrease the direct incidence, without losing the view of the outside. Only in cases of direct solar incidence, double roller shades are proposed, with the possibility of dimming light using a semi-see-through fabric. In Room 2, a pergola was incorporated into an existing structure attached to the Northeast facade.

- Increased airtightness of the SUM spaces and corridors through a translucent enclosure with Profilit – U double glazed self-supporting profile system, complemented with upper ventilation grilles, thus closing the opening system with fixed horizontal sunshades that were originally permeable to weather agents. In addition, upper projection windows with 3+3 laminated glass were incorporated along the northwest corridor, increasing the diffused light towards the rooms, and DVH windows with thermal bridge breakers in the openings to the outside.

- Regulation of air renewals (reduction or increase), according to the requirements of each classroom, considering that the type of ventilation proposed has a higher degree of airtightness and allows better management of natural ventilation.

Table 4 shows the dimensional variables of the original model of Room 2, with northwest-facing glazed areas, and the improvement proposals developed for the two solar absorbance values.

Revista Hábitat Sustentable Vol. 12, N°. 1. ISSN 0719 - 0700 / Págs. 24 -43
https://doi.org/10.22320/07190700.2022.12.01.02

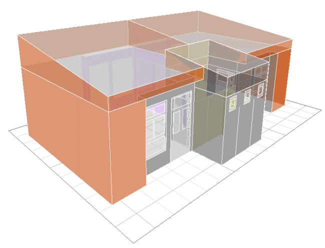
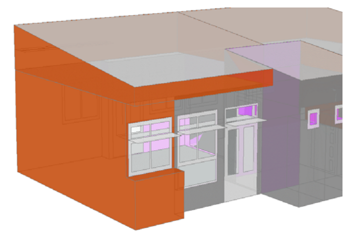
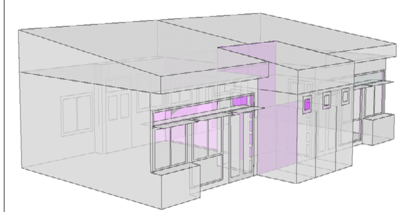
Room 2 – JI 174	ORIGINAL	Pg4 abs 0.65	Pg4 abs. 0.25
DIMENSIONS: Width: 7.20 m Length: 7.20 m Height: 3.00 m			
NORTHWEST FAÇADE OPENINGS SYSTEM	Top and central pane window with 2 sliding sheets and/or a fixed lower pane. Door with a fixed upper glazed pain and 2 folding glazed sheets	Top and central pane window with 2 sliding sheets and/or a fixed lower pane Sunken window with a 2 sliding sheet central and upper pane and/ or Door with a fixed upper pane and 2 folding sheets with fixed glass that total 1.53m2	2 sliding sheet windows and a fixed lower pane Sunken window with 2 sliding sheets Upper window pane with running projection. Door with 2 folding sheets with fixed glazing that total 1.80 m2
PROTECTION DEVICES	Eaves and flashes	External light shelves along the upper openings of 0.50 m width and interior of 0.40 m wide, eave projections, and side pergola	External light shelves along the upper openings of 0.50 m width and interior of 0.40 m wide, eave projections, and side pergola
OPENING PROPORTION (m)	Window: Width: 1.60; Height: 1.90 Door: Width: 1.4; Height 2.5	Window: Width: 1.60; Height: 1.90 Sunken window: Width: 1.60; Height 1.30 Door: Width: 1.4; Height 2.5	Window: Width: 1.60; Height: 1.90 Sunken window: Width: 1.60; Height 1.60 Sliding window: Width 5.10; Height: 0.45 Door: Width: 1.4; Height 2.0
GLAZING EF. AREA Without frames (m2)	3.29	5.05	7.43
WEIGHTED AVERAGE SOLAR ABSORBANCE (α)	0.57	0.65	0.25
TOTAL ENVELOPE AREA (envelopeA)	124.81	124.81	124.81
FLOOR AREA (m2)	44.52	44.52	44.52
FAÇADE AREA (m2)	16.2	16.2	16.2
GA/FA(%)	7.4	11.3	16.7
GA/FacA (%)	20.3	31.2	45.9

Table 4. Dimensional variables of the original model and the improvement proposals with different solar absorbance values. Source: Preparation by the authors.

Revista Hábitat Sustentable Vol. 12, N°. 1. ISSN 0719 - 0700 / Págs. 24 -43
https://doi.org/10.22320/07190700.2022.12.01.02

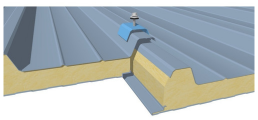
ILLUSTRATIVE DETAILS	GENERIC PROPOSAL (pg4)	Esp. (m)	Global Loss Coeff U (W/m2°C)	U (W/m2°C) IRAM Medium Level
	CEILING Self-supporting sheet metal plate with internal insulation thermal transmittance Coefficient (k) = 0.44 W/ m2°C * Reflective exterior finish.	0.081	0.4	0.45 (IRAM 11605: 1996)
	DOUBLE WALL: a sheet of ordinary brick, 0.12 m thick; insulation of 0.03 m thick expanded polystyrene (15 kg/m3); 0.12 m thick brick sheet finished with thick and thin plaster inside.	0.30	0.8	1.1 (IRAM 11605: 1996)
	DVH WINDOWS, laminated (6+12+6); aluminum profiles with RPT (U = 2.85 W/m2°C). Shading coefficient = 0.72; Visible transmittance = 0.81; Refractive index 1.526. * Devices for controlling and distributing daylight (eaves - light shelves)	0.024	2.8	from 2.01 to 3.00 (Medium-Level K4 IRAM 11507 4:2010)
	TRANSLUCENT Profilit / U-Glass double ENCLOSURES of 0.40 x 2.60 m and 4 mm thick; aluminum profiles with RPT. Shadow coefficient = 0.72; Visible transmittance = 0.81; refractive index 1.526.	0.082	2.8 (day and night	

Table 5. Properties of the Generic Proposal of the JI 174 entered into Simedif. Source: Preparation by the authors.

- **Treatment of the opaque and glazed envelope using medium thermal inertia solution**s of known use in the NEA, following global loss coefficient (U) values recommended by the IRAM 11605: 1996 Standards for summer (most unfavorable situation) at the Middle level (B), and the design recommendations for Zone Ib, IRAM 11603: 2012. In this way, U = 0.8 W/m^2 °C was calculated for walls; U = 0.4 W/m^2 °C for ceilings; and U = 2.8 W/m^2 °C for windows, without the average level K4 (from 2.01 to 3.00 W/m2°C) (IRAM 11507 4: 2010). Table 5 details the generic proposal of the building with its characteristics entered into Simedif.

RESULTS OF THERMO-ENERGETIC SIMULATIONS

For each classroom analyzed, the temperature evolution of the respective proposals simulated using Simedif, obtained in November was plotted, comparing it with those measured from the original building (Figures 14 and 15). The green dotted line indicates the comfort limits established for the statistical analysis (20 - 27 °C) and the yellow dotted line indicates the maximum regional comfort limit (29 °C).

It is observed that the temperatures of the proposals remain most of the time within the comfort zone, with Room 3 (southeast) being in better conditions. Room 2 (northwest), leaves the regional comfort zone between 1 pm and 7 pm, but the temperature decreases considerably with respect to the original situation since, because as the northeast façade is fully exposed to solar radiation, it presented greater gains.

Comparing the original situation with the results of the *pg4* improvement proposal (= 0.25) considered optimal, the following thermal improvements were

Revista Hábitat Sustentable Vol. 12, N°. 1. ISSN 0719 - 0700 / Págs. 24 -43
https://doi.org/10.22320/07190700.2022.12.01.02

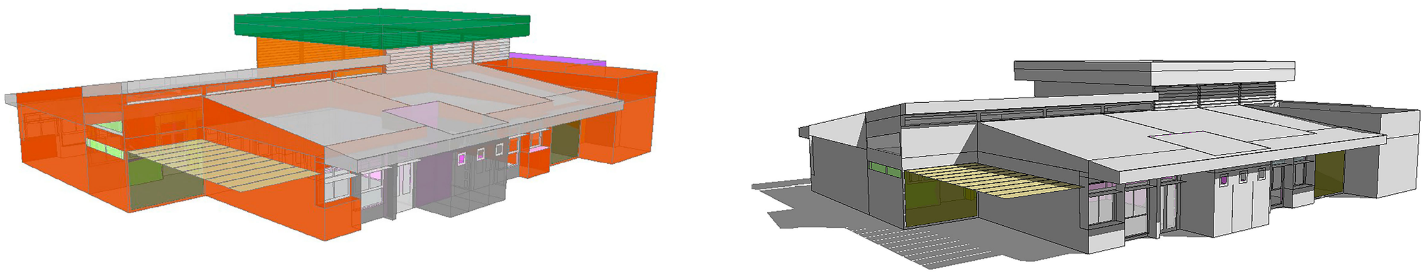


Figure. 13. Left. Model pg4 (= 0.65) – Right. Model pg4 (= 0.25). Source: Preparation by the authors.

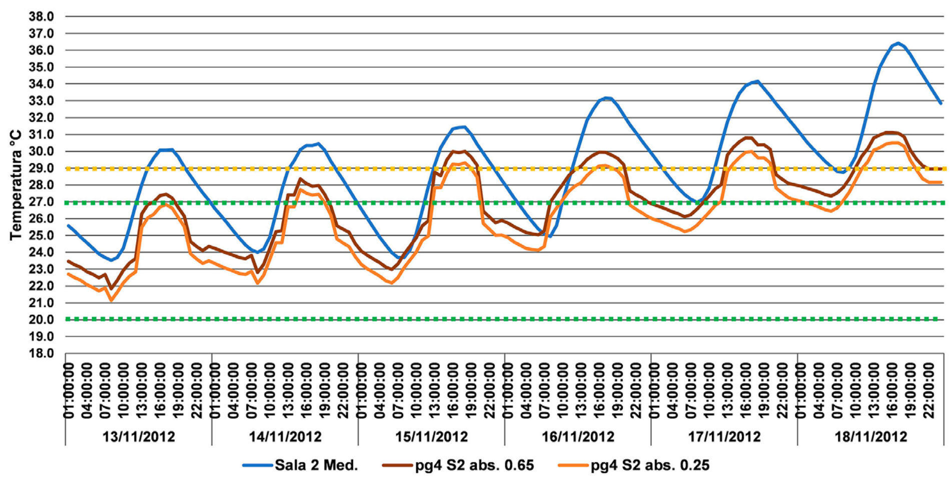


Figure 14. Evolution of simulated temperatures with the generic proposals (pg4), in contrast to the measured temperature (Room 2). Source: Preparation by the authors.

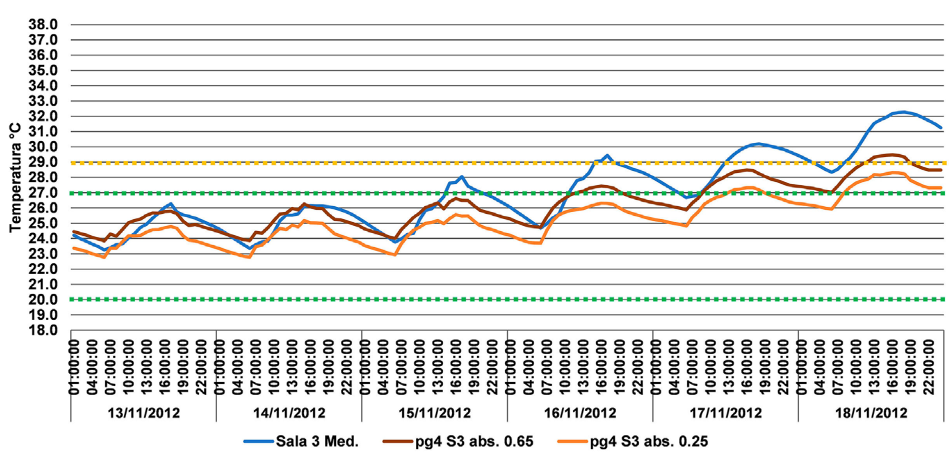


Figure 15. Evolution of simulated temperatures with the generic proposals (pg4) in contrast to the measured temperature (Room 3). Source: Preparation by the authors.

obtained in the analyzed November period: starting from a measured absolute maximum temperature of 36.4 °C and an average temperature of 29.0°C in Room 2, a reduction of 5.9°C and 3.0°C, respectively, was achieved. Based on a measured absolute maximum temperature of 32.3°C and an average temperature of 27.0°C in Room 3, a reduction of 4.0°C and 1.8°C, respectively, was achieved (Table 6).

These improvements in indoor temperatures were reflected in a drastic decrease in cooling loads in both proposals, verified by simulations with thermostatization (25°C) in Simedif, as well as the hours of discomfort where conditioning is required. Table 7 compares the maximum cooling requirements of both proposals with respect to the original simulated model, seeing a reduction of 72% for Room 2 and 51% for Room 3 with the proposed *pg4*

Revista Hábitat Sustentable Vol. 12, N°. 1. ISSN 0719 - 0700 / Págs. 24 -43
https://doi.org/10.22320/07190700.2022.12.01.02

		Temp. Measurement (°C)	pg4 S2 - 0.65 (°C)	pg4 S2 - 0.25 (°C)	Dif. pg4 S2 - 0.65 (°C)	Dif. pg4 - 0.25 (°C)
ROOM 2	MAXIMUM	36.4	31.1	30.5	5.3	5.9
	AVERAGE	29.0	26.9	26.1	2.2	3.0
ROOM 3	MAXIMUM	32.3	29.5	28.3	2.8	4.0
	AVERAGE	27.0	26.2	25.2	0.7	1.8

Table 6. Comparison of measured maximum and average temperatures and simulated proposals. Source: Preparation by the authors.

LOCAL	gA Orient	Original (W)	pg4 0.65 (W)	pg4 0.25 (W)	Difference (Original - pg4 0.65)	Difference (Original - pg4 0.25)	% Reduction pg4 0.65	% Reduction pg4 0.25
ROOM 2	NO	10600	3084	2985	7516	7614	71	72
ROOM 3	SE	2740	1455	1331	1285	1410	47	51

Table 7. Reduction of cooling loads, November period. Source: Preparation by the authors.

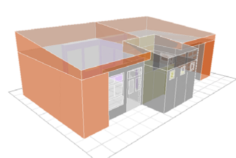
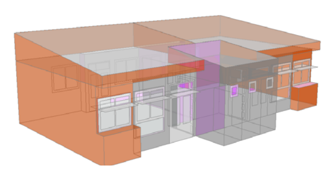
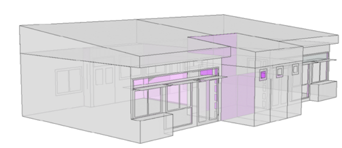
JI 174 NOVIEMBRE						
	MEDIDA		pg4 abs. 0.65		pg4 abs. 0.25	
AVERAGES	Ilum. (Lux)	Temp. (°C)	Ilum. (Lux)	Temp. (°C)	Ilum. (Lux)	Temp. (°C)
Room 2	77	27,8	487	26,3	599	25,6
Room 3	109	25,2	557	25,6	572	24,6
RANGOS	Ilum. (Lux)	Temp. (°C)	Ilum. (Lux)	Temp. (°C)	Ilum. (Lux)	Temp. (°C)
Room 2, 9:00 h.	114	24,2	476	23,3	563	22,6
Room 2, 13:00h.	201	28,9	551	27,4	648	26,7
Room 2, 16:00h.	319	30,3	433	28,1	585	27,5
Room 3, 9:00 h.	99	23,8	610	24,7	564	23,9
Room 3, 13:00h.	130	25,5	596	26,0	630	24,9
Room 3, 16:00h.	99	26,2	466	26,1	523	25,0

Table 8. Comparative results of thermal-light simulations (11/14/2012) on average and by hourly ranges.
Source: Preparation by the authors.

(= 0.25). The remarkable improvement obtained in Room 2 is verified by reducing the exposed area of the opaque envelope and the solar absorption of the exterior surfaces.

THERMAL-LIGHT COMPATIBILITY OF RESULTS

When analyzing the thermal-light compatibility in the three evaluated schedules (9 am, 1 pm, and 4 pm) on the sunniest day, Nov. 14th, 2012 (Table 8), it is noted that through the improvement proposals, the increase in the illuminance averages was verified with respect to the original model that did not reach the minimum values. The *pg4* (= 0.65) enters the thermal-luminous comfort zone (between 20°C and 27°C and from 300 to 500 lux), while the *pg4* (= 0.25) slightly exceeds the visual comfort limit given the higher GA/FA percentage, although without leaving the thermal comfort zone. Even though this would not generate glare problems, since a maximum illuminance of 750 lx is accepted, the values could be corrected through the use of translucent internal curtains

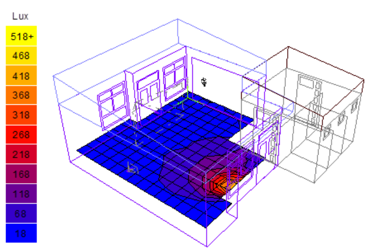
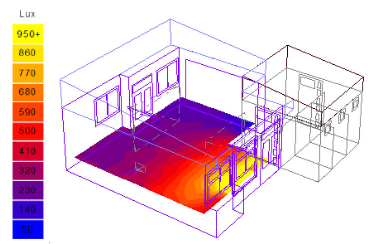
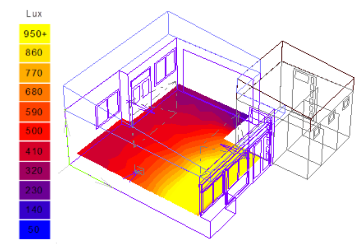
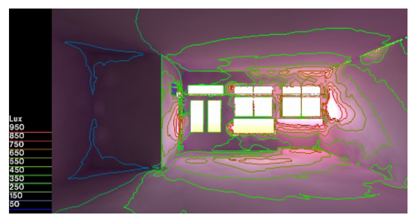
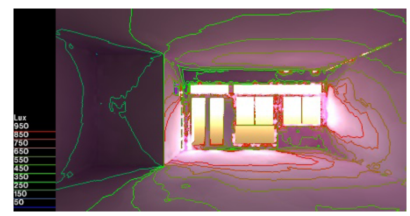
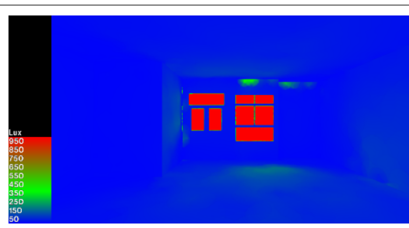
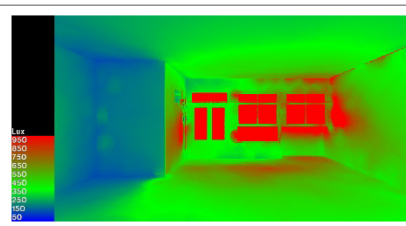
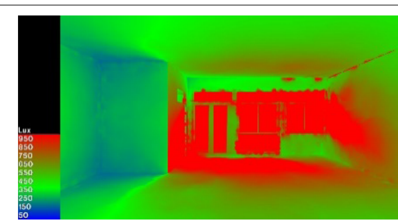
ORIGINAL MODEL	IMPROVED pg4 abs. 0.65	IMPROVED pg4 abs. 0.25
		
		
		
Ilum. = 114 lx	Ilum. = 476 lx	Ilum. = 585 lx

Table 9. Comparative results of thermal-light simulations on average - Room 2 (Day 14/11/2012 – 4 pm). Source: Preparation by the authors.

at times of greater solar incidence. As an example, Table 9 shows the visualizations obtained for the original Room 2 model and the improved ones, on the sunniest day, Nov. 14th, 2012 at 4 pm, when the sun hits the northwest facade.

CONCLUSIONS

The verification made using dynamic simulation models, calibrated with onsite measurements, allowed demonstrating the relevance of the glazed areas proposed for different solar absorbance values of the outside exposed surfaces of the case study, and to preliminarily validate the estimation methodology of the Glazing Factor (*Fv*) for the Compact Kindergarten Typology. This connected the most important variables in play (*Av*, α and *envelopeA*) and makes it possible to determine glazed areas that would lead to optimal thermal and light behavior.

In particular, a reduction of cooling requirements of up to 72%, in November, the most unfavorable for a school activity, was obtained by lowering the solar absorbance of outdoor surfaces to 0.25 (light colors), with a glazed area by the floor area ratio of 17 % (northwest and southeast), that allowed significant improvements in the spatial distribution of daylight, a key resource for the integrated development of children in Initial Schooling Level.

This finding extends that established by the current Resistencia Construction Regulations, which determines only a minimum *gA* of 10% of the floor area, without considering the intermediate orientation of the city, or the other project variables (total envelope area and exterior solar absorption). In this way, the *gF* estimation tool can become a valuable resource for professionals in the education sector, as well as for updating municipal or provincial regulations in the NEA Region.

However, the iteration process to calculate other typologies different from the reference one could be laborious since the *gF* correlations were obtained with limited input data, so it will be necessary to continue testing other initial-school-level typologies and in other possible orientations, to expand the database and improve the operation of the corresponding correlation, insofar as it constitutes a feasible modification methodology with new inputs.

Considering the compatibility of the proposed thermal and light improvements, the importance of the optimized solar protection design of window devices, and integrated environmental regulation systems are highlighted, which together with the treatment of the opaque envelope, and the morphological layout of the building, allow its adaptation to a wide range of climatic conditions and responsible for the use of such as powerful renewable energy source in the NEA Region, as solar is.

The degree of fit obtained regarding the data taken onsite, from the dynamic simulation models made using the Simedif software, in real occupation conditions, with mean deviations of 0.6°C (RMSE) and errors (MAPE) that do not exceed 2%, contributed to the accuracy of the results. Likewise, the Ecotect Radiance interface was a contribution, with average errors of 46 Lx (RMSE) and 18% (MAPE), admissible in terms of illuminances. This makes it feasible to test other periods not yet measured reliably, based on weather data collected in the urban microclimate of Resistencia.

Facing the future global warming scenarios, and the evident need for updating comfort standards at a local and Latin American level, but also taking into account the particularities of different educational levels, in this case, the Initial Schooling Level, the results of this research represent a scientific level record, available for its main beneficiary, the Ministry of Education, Culture, Science and Technology of the Province of Chaco, which may well be extended to other regions with a Very Warm – Humid subtropical climate, in pursuit of the sustainable design school spaces.

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